United States Environmental Protection Agency

Air and Energy Engineering Research Laboratory
Research Triangle Park NC 27711

Research and Development

EPA/600/S7-85/047 Nov. 1985

EPA

Project Summary

Assessment of NO_x Emission Factors for Direct-Fired Heaters

C. R. Newman

Industrial fuel use in non-boiler applications amounted to about 60 percent of total industrial fuel consumption in 1980. Historically, air pollution control of these sources has focused on emissions of particulates and sulfur compounds with much less emphasis on emissions of oxides of nitrogen (NO_x). NO_x, however, currently are felt to play a role in the formation of acid precipitation.

The increasing use and potential for use of preheated combustion air for energy conservation may result in increased emissions of NO_x from direct-fired process heaters. Limited data show that NO_x emission rates rise as combustion air temperature increases. Studies indicate that a significant market for high temperature heat recovery equipment for use with many types of industrial sources will exist as they become proven and are applied to both new and existing sources. If these devices, which can preheat combustion air to 2000°F* and beyond, are applied extensively, nationwide emissions of NO_x could increase significantly.

Under this work assignment, available data on emission factors for major categories of direct-fired heaters were reviewed. Systematic studies were analyzed to develop emission factors for NO_x at various levels of combustion air preheat used in major energy-consuming industries.

This Project Summary was developed by EPA's Air and Energy Engineering Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

*Readers more familiar with the metric system may use the conversion factors at the back of this Summary.

Introduction

The objective of this report is to provide technical information on NO_x emissions attributable to energy-intensive direct-fired process heaters. Specific tasks undertaken to quantify current NO_x emissions and trends in NO_x resulting from technology changes were:

- Define energy-intensive direct-fired process heaters.
- Describe the fundamentals of NO_x formation.
- Investigate technology changes leading to energy conservation.
- Determine the effect of energy conservation techniques, primarily combustion air preheat, on NO_x emissions.
- Develop NO_x emission factors for direct-fired process heaters employing various levels of combustion air preheat.

Energy-Intensive Heaters

Several energy-intensive industrial processes were identified as capable of producing and using high-temperature preheated combustion air: steel reheat furnaces; steel soaking pits; aluminum reheat furnaces; aluminum melting furnaces; steel forging furnaces; annealing furnaces; titanium melting furnaces; nickel melting furnaces; cement kilns; and glass melting furnaces. Although preheated combustion air presents opportunities for energy savings in these industrial process heaters, it also has the drawback that increased combustion air temperatures lead to increases in thermal NO_x emitted from these stationary sources. NO_x emissions could increase from an estimated 6.73 million tons in 1980 to an estimated 8.31 million tons in 1990 due in part to combustion air preheat.

Fundamentals of NO_x Formation

Regardless of the type of combustion device, NO_x are formed in combustion processes by the thermal fixation of atmospheric nitrogen and by the conversion of fuel-bound nitrogen. Total NO_x emissions and the contribution of each mechanism to the total depend on the heater design, heater operating conditions, and the type of fuel burned.

Combustion generates high temperatures that result in molecular dissociation of the oxygen in the combustion air. The separate oxygen atoms react with many other atoms in the combustion reactions, but some react with the otherwise stable N_2 molecule to form NO.

By using thermodynamic and chemical kinetic analyses, it is possible to model approximately the controlling influences of combustion stoichiometry, temperature, and residence time, assuming one-dimensional homogeneous air/fuel flow. Explicitly, the theoretical model shows that the rate of formation of NO is sensitive to the mole fractions of oxygen and nitrogen. Also, the model predicts the extreme sensitivity of NO formation to temperature: as the temperature increases, the rate constants increase exponentially. Since preheat of combustion air can increase the peak flame temperature in the combustion zone, air preheat can increase thermal NO formation.

On practical equipment, combustion fundamentals of thermal NO formation include mixing, turbulence, heat transfer, and composition, along with temperature in the combustion zone. Thus, a quantitative determination of thermal NO formation at various levels of combustion air preheat must be based on specific furnace designs and operating parameters.

In general, all fuel-bound nitrogen can be assumed to be converted rapidly to NO. As with thermal NO formation, the conversion of fuel nitrogen depends on combustion conditions. This dependency, however, has been found to be less sensitive to design and operating parameters. For this analysis, it is assumed that all fuel-bound nitrogen is converted to NO with no effect by combustion air temperature.

Process Heater Design and Operation

The primary function of process heater systems is to provide controlled efficient conversion of the chemical energy of fuel into an energy form that can be transferred as heat to process fluids. Process heaters do this by introducing the fuel and air for combustion, mixing these reactants, igniting the mixture, and distributing the flame envelope and the products of combustion. A process heater should function so that the fuel and air input is ignited and burned continuously and immediately upon its entry into the furnace. The total fuel burning system required to do this consists of subsystems for air handling, fuel handling, ignition, and combustion product removal, plus the burners and the furnace. Assuming the burners are chosen properly in furnace system designs, trends in formation of NO_x can be evaluated for many types of furnaces by analysis of a few basic burner types.

As industries seek ways of reducing operating costs by fuel conversion, operating parameters may be adjusted for optimum fuel conservation. Optimization of fuel use using heat recovery techniques, however, may lead to increases in pollutant emissions. Currently, one of the more prevalent heat recovery techniques involves preheating combustion air to achieve greater furnace efficiency. This air preheat also increases NO_x formation by increasing the temperature in the combustion zone. A systematic study of energy-intensive industries reveals two broad, distinct classifications of industrial processes capable of using preheated combustion air. The steel, aluminum, and other metal processing industries and petroleum refining industries use baffle burners capable of using air preheat in the range of 800-1200°F. Furnaces common in the glass manufacturing and cement manufacturing industries can use preheated combustion air in the range of 1600-2200°F.

Several major companies are involved in the manufacture of burners capable of accepting high temperature combustion air. To evaluate the effect of combustion air preheat on NO_x emissions from direct-fired process heaters, burners must be selected as representative of those that are used or potentially could be used for the specific furnaces under consideration. Steel reheating processes, steel soaking processes, and aluminum melting processes can be represented by the Bloom hot air baffle burner, based on the extent of its current use in these processes. Because of process similarity and furnace design and operation, the Bloom hot air baffle burner would also be representative of the nickel and titanium melting furnaces. The Bloom burner is also used in refinery process heaters. The North American refractory-lined burner is used in the glass industry and, because of similar process heat requirements, it may also be considered as representative of burners used in cement kilns. Thus, by analysis of the various operating conditions of two burners, the effect of combustion air preheat on NO_x emissions from energy-intensive processes can be estimated.

Effect of Heater Operation on NO_x Emissions

NO_x emission factors have been developed at various combustion air preheat levels for two furnaces representing the broad classifications of direct-fired heaters used in energy-intensive industries, for a theoretically based model furnace, and for prototype low-NO_x burners capable of industrial use. Systematic studies by the Institute of Gas Technology under contract to the Gas Research Institute and Southern California Gas Company provided the basis for development of these emission factors. These results were used to develop NO_x emissions factors for the range of process heaters used in energy-intensive industries at various levels of combustion air preheat. Table 1 gives the results of this analysis.

Conversion Factors

Readers more familiar with the metric system may use the following factors to convert to that system:

Nonmetric	Times	Yields Metric
Btu	1.055	kJ
°F	5/9(°F - 32)	°C
lb	0.454	kg
ton	907.2	kg

Table 1. Emission Factor Summary[a]

Furnace	Fuel	NO_x Emission Factors, lb $NO_2/10^6$ Btu Preheat Temperature, °F			
		800	1200	1600	2000
Steel Reheat	Coke Oven Gas	0.34	0.72	1.40	3.20
	Natural Gas	0.34	0.72	1.40	3.20
Steel Soaking Pit	Coke Oven Gas	0.34	0.72	1.40	3.20
	Natural Gas	0.34	0.72	1.40	3.20
Aluminum Reheat	Residual Fuel Oil	0.64	1.02	1.70	3.50
	Natural Gas	0.34	0.72	1.40	3.20
Aluminum Melting	Residual Fuel Oil	0.64	1.02	1.70	3.50
	Natural Gas	0.34	0.72	1.40	3.20
Steel Forging	Natural Gas	0.34	0.72	1.40	3.20
Annealing	Natural Gas	0.34	0.72	1.40	3.20
Titanium Melting	Natural Gas	0.34	0.72	1.40	3.20
Nickel Melting	Natural Gas	0.34	0.72	1.40	3.20
Cement Kiln	Natural Gas	--	--	0.80	1.80
Glass Melting	Natural Gas	--	--	0.80	1.80
Refinery Process	Natural Gas	0.34	0.72	1.40	3.20

[a]*These emission factors are adequate for use in emission inventory preparation. Application of these factors to specific heaters are subject to the following limitations:*

(i) The emission factors are based only on experimental data from two types of industrial furnaces, and they are suggested for application to other industrial furnaces based on similarities in furnace design and operating conditions.

(ii) Except for the glass melting furnace and cement kiln, the emission factors for 1,600 and 2,000°F air preheat temperatures are extrapolated values.

(iii) For residual fuel oil, the listed NO_x emission factors are for 0.3 weight percent N content and 19,600 Btu/lb heating value, assuming 100% conversion of fuel N to NO.

C. R. Newman is with GCA/Technology Division, Chapel Hill, NC 27514.
***J. David Mobley** is the EPA Project Officer (see below).*
The complete report, entitled "Assessment of NO_x Emission Factors for Direct-Fired Heaters," (Order No. PB 86-119 112/AS; Cost: $11.95, subject to change) will be available only from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650

The EPA Project Officer can be contacted at:

Air and Energy Engineering Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

United States
Environmental Protection
Agency

Center for Environmental Research
Information
Cincinnati OH 45268

Official Business
Penalty for Private Use $300

EPA/600/S7-85/047